RADIOLOGICAL AND CHEMICAL STUDIES OF THE GROUND WATER AT ENEWETAK ATOLL

I. Sampling, Field Measurements, and Analytical Methods

K.V. Marsh
K.M. Wong
G. Holladay
V.E. Noshkin
R. Buddemeier

September 26, 1975

Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48

LAWRENCE LIVERMORE LABORATORY
University of California/Livermore

Distribution Category
UC-41

LAWRENCE LIVERMORE LABORATORY
University of California/Livermore, California/94550

UCRL-51913 Pt. 1

RADIOLOGICAL AND CHEMICAL STUDIES OF THE GROUND WATER AT ENEWETAK ATOLL

I. Sampling, Field Measurements, and Analytical Methods

K. V. Marsh, K. M. Wong, G. Holladay, and V. E. Noshkin

Lawrence Livermore Laboratory

and

R. Buddemeier

University of Hawaii, Honolulu, Hawaii

MS. date: September 26, 1975

Contents

RADIOLOGICAL AND CHEMICAL STUDIES OF THE GROUND WATER AT ENEWETAK ATOLL

1. Sampling, Field Measurements, and Analytical Methods

Abstract

A research program to study the ground water on several of the islets in the Enewetak Atoll is being conducted jointly by Lawrence Livermore Laboratory and the University of Hawaii under the sponsorship of ERDA Division of Biology and Environmental Research. The purpose is to provide data characterizing the ground water for possible use by returning Marshallese and to investigate the hydrology and recycling of radionuclides in an atoll environment. This first of a series of reports describes the sampling locations, field operations, and methods of analysis.

Introduction

In coordination and collaboration with investigators from the University of Hawaii, a program was initiated at Enewetak Atoll in 1974 to study systematically the hydrology and ground-water geochemistry on selected islands of the atoll. Chemical and radiochemical data will be provided for water quality assessment on those islands designated for resettlement and for use together with other data to interpret the mechanisms and rates of recharge and disappearance of radionuclides, nutrients and major elements in the ground water system.

Since the resettlement of the atoll is imminent, it is necessary to begin summarizing our available preliminary results. Because of the vast amount of data collected during this program it will be necessary to publish independent reports on our results almost island by island.

The information contained in this report is for reference and will not be duplicated in future reports. Following sections describe the locations and characteristics of each of the sampling wells, the field instruments and sampling procedures, and the analytical methods. Appendix A gives the definition of potable water recommended by the U.S. Public Health Service.

Background

An extensive radiological survey of Enewetak Atoll was initiated in the fall of 1972 and was concluded in the spring of 1973. The purpose of the survey was to identify the quantities and distributions of the residual radioactivities in the atoll (the site of nuclear test series during the 1940's and 50's) and to examine the major components of most significance to radiological dose calculations. The survey results were published in October, 1973 as NVO-140.[1] It was concluded that the terrestrial food chain could potentially contribute far greater doses to a returning population than could external radiation, the marine food chain or inhalation.

The codes used for assessing dose from terrestrial radioactivity considered radioactive decay to be the only mechanism for removing radionuclides from the environment. Rainfall runoff, penetration into the soil surface, and migration through the ground water aquifers may also be important loss mechanisms, however. Data collected during the survey were insufficient to evaluate the importance of these other pathways.

It was also assumed that the Enewetak people, upon return to their atoll, will continue their practice of using catchment rain water for drinking and that underground lens water will not be a part of their diet. It is recognized, however, that if fresh ground water were available it could supplement the cistern supply or be used for agricultural or household purposes. Wells on Bikini Atoll are being used in this way at present.

In order to assess the water quality at Enewetak and to develop a total budget of mass flow through the ground water of the atoll, we proposed to drill a total of 14 wells, some on islands designated for rehabilitation and others on islands exhibiting a variety of radiological burdens.

A series of seismic experiments initiated at Enewetak in late 1973 by the USAF under the code name "EXPOE" involved drilling and geological core recovery. An agreement was negotiated enabling EXPOE field personnel to drill fourteen 10-m-deep wells and case the holes with 4-in. slotted PVC pipe for our study. EXPOE was also drilling and casing a number of 2-in. wells for their program. During the early drilling operations in February 1974, Dr. Buddemeier suggested that the remaining 2-in. EXPOE pipes also be slotted to provide us a number of additional sampling locations.

Drilling and casing was completed in late June 1974. Our first field program was in May 1974, and the wells completed at this time were sampled. Further sampling programs were conducted during July-August, 1974, January-February, 1975, and October, 1975. Interim trips were made in November, 1974, April-May, 1975, and July, 1975 to relocate tidal gauges and profile the water columns.

Because of the extensive research supported in the Marshall Islands by the Atomic Energy Commission, operation of a scientific research vessel (LCU-26, operated by the U.S. Army) was funded by ERDA in FY1975 and 76. This vessel was utilized on each major expedition to the atoll and we can most emphatically state that our program could not have been implemented without this support. Specifically we wish to acknowledge the assistance and cooperation provided us during each expedition by Captain Peter Beusasco and the crew of LCU-26.

LLL personnel designed and developed the necessary water-sampling equipment and are responsible for the radiochemical analysis and field salinity studies of the ground water. Dr. Buddemeier of the University of Hawaii is assessing major and minor elements, nutrients, and bacteria in the water and is maintaining tide and rain gauges on several islands.

Well Locations and Descriptions

When the original plans for the Enewetak ground-water investigation were laid in November 1973, the number and locations of the wells were chosen with consideration for both scientific and practical factors. Information was desired on the chemical composition, hydrology and quantity of fresh or brackish water on various islands as a function of their size, shape and position on the atoll relative to the type of underlying reef. Radiological data were desired, especially on those islands to be resettled, but also to gain an understanding of the distribution and recycling of radionuclides in the atoll environment. At the same time, more mundane factors such as cost, accessability of the islands to drilling equipment, transportation, scheduling and weather had to be taken into account.

Originally, a total of 14 wells on 7 different islands were planned for ground water studies. They were to be drilled about 10 m deep and cased with 4-in. polyvinylchloride (PVC) pipe, slotted more or less at random but with at least one 6-in.

slot per lineal foot, and capped to exclude light and rain.

One 4-in. well each on Belle, Ursula, David, Elmer, and Leroy, three on Yvonne, and six on Janet were drilled by EXPOE personnel. About half-way through the drilling program it developed that many of the holes they were drilling for their own core recovery could be cased with

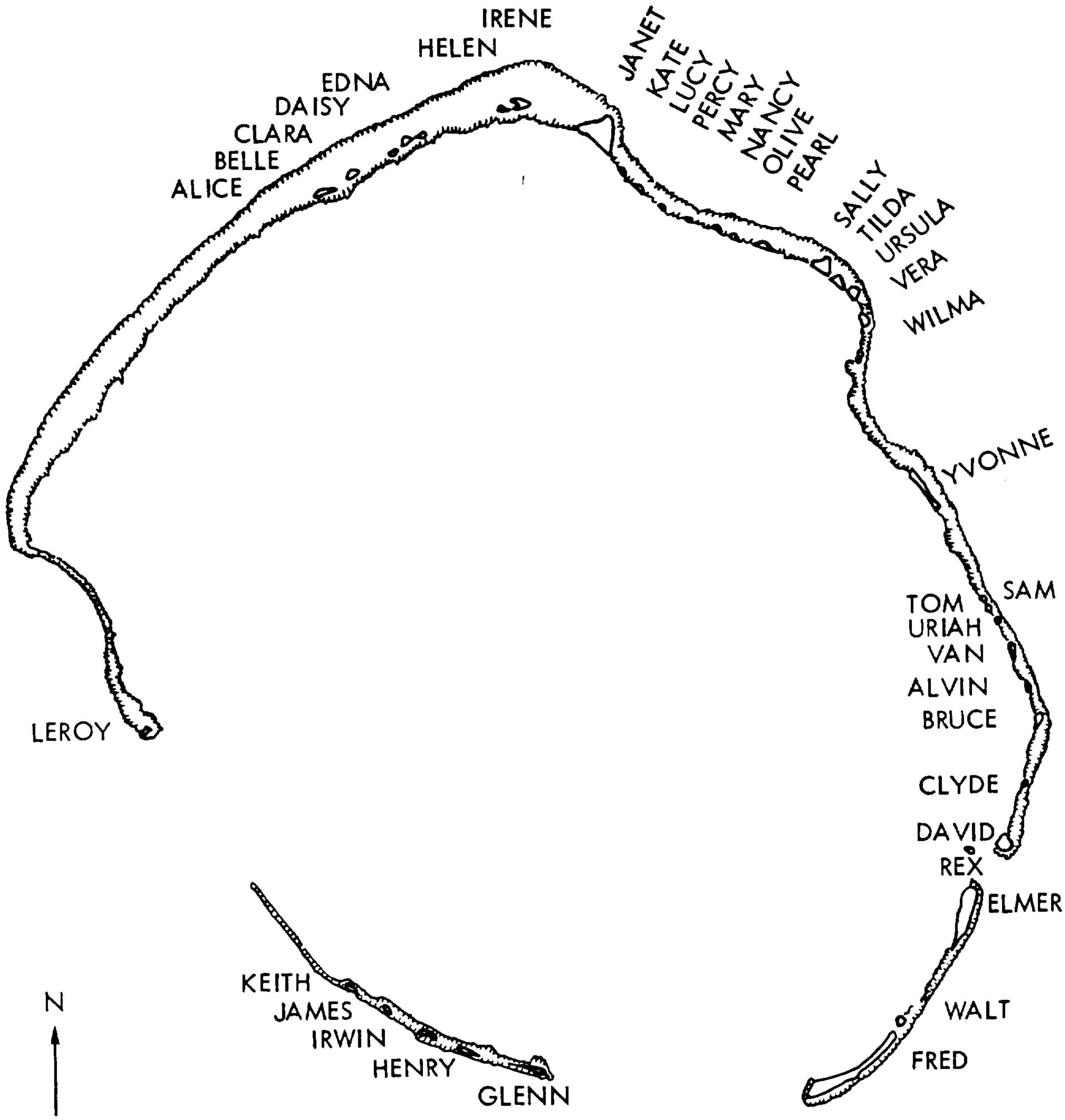

Fig. 1. Enewetak Atoll.

2-in. slotted PVC. This made 19 additional wells available to the ground water program.

Two sets of wells were thus emplaced and labeled with either the prefix "A" (for AEC) or "X" (for EXPOE), two letters representing the (Marshallese) name of the island, and a number. Thus, AEN-1 is the label of a particular 4-in. well on Enjebi (Janet), while XRU-1 is a 2-in. hole on Runit (Yvonne). The "A" wells were all drilled with an organic drilling fluid, Revert,* containing no clay minerals that might have undesirable effects on trace element concentrations. The "X" wells were drilled with a conventional bentonite drilling mud.

Figure 1 shows the general features of the atoll. In the following descriptions, surveyed ground elevations are labeled "(S)" and are ±0.35 m. All others are estimated. Fallout is reported in terms of dose rate one hour after detonation (H + 1 h).

BELLE (Bokombako)

This island (Fig. 2, 0.19 km^2) is one of the most contaminated islands on the atoll. It received a total of 3382 R/h of fallout from 25 events. Radiation levels 1 m above the ground in 1972 were 65-130 μR/h over most of the island, falling to 1-2 μR/h on the beaches. The two chief contributors to the background gamma radiation are ^{137}Cs and ^{60}Co. Vegetation is dense over most of the island.

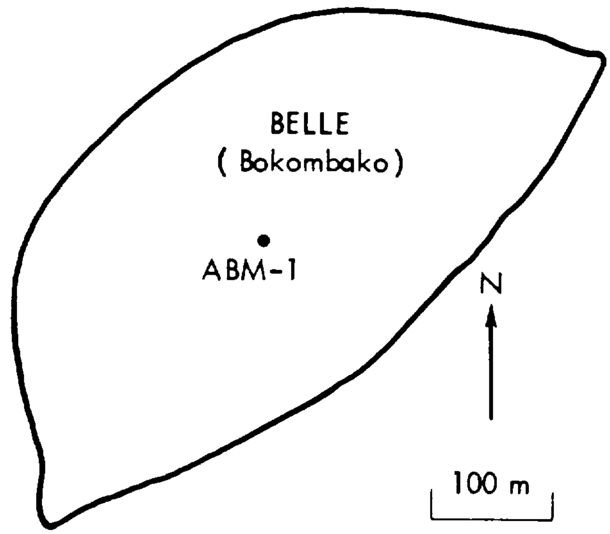

Fig. 2. Well location on Belle (Bokombako), Enewetak.

Only one useful well, ABM-1, was drilled on Belle. It was located approximately in the center of the island and drilled on 2/17/74 to a depth of 11 m and cased to total depth. The ground elevation is 2 m above mean sea level (AMSL).

JANET (Enjebi)

Janet (Fig. 3), with an area of 1.11 km^2, is the largest island in

*Trademark of the Johnson Division of Universal Oil Products Company. Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exclusion of others that may be suitable.

the northern part of the atoll and one of the most contaminated. Twenty-three tests on nearby islands and three tests detonated on Janet itself resulted in a total fallout of 3501 R/h. Present levels of

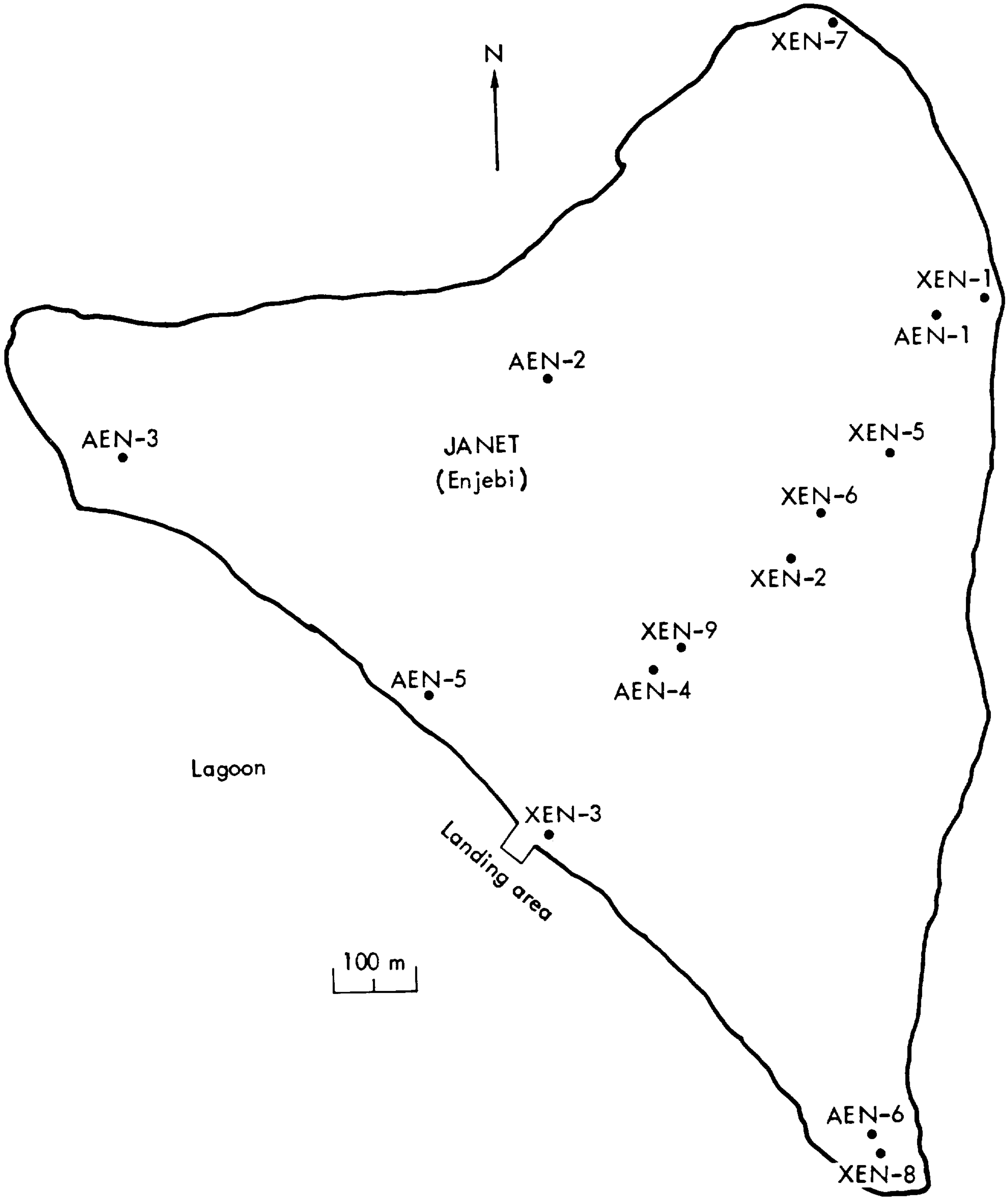

Fig. 3. Well locations on Janet (Enjebi), Enewetak.

contamination caused the background to range from an average of 50-60 μR/h in the interior of the island down to about 5-10 μR/h on the beaches. As on Belle, ^{137}Cs and ^{60}Co are the chief contributors to the gamma background.

From its size and shape, Janet would be expected to support a large fresh water lens. Native Marshallese also reported that, at least up until World War II, wells provided fresh water for drinking and agriculture. Since Janet is also a principal candidate for resettlement by the Marshallese, it was decided to make use of as many wells as possible for the ground water investigations. In addition to the six AEN wells, eight XEN wells were completed on the island.

XEN-1

Located seaward of the east end of the old runway, about 30 m from the beach, 190 m seaward of AEN-1. Drilled from 1/14/74 to 1/28/74 to a depth of 89.5 m and cased to total depth. Ground elevation is 1.93 m AMSL(S).

AEN-1

Located near the east end of the runway about 190 m inland from XEN-1 and about 220 m inland from the seaward shore. Drilled 2/19/74 to 2/20/74 to a depth of 11.5 m and cased to total depth. Ground elevation: 2.32 m AMSL(S).

AEN-2

Located approximately the middle of the runway, about 225 m south of the beach along the north edge of the island. Drilled 2/20/74 to 2/21/74 to a depth of 11.9 m and cased to total depth. Ground elevation is 2.32 m AMSL(S).

AEN-3

Located near the west end of the runway about 150 m inland from the lagoon near the northwest tip of the island. About 300 m from the beryllium storage bunker. Drilled 2/21/74 to 2/22/74 to a depth of 12.2 m and cased to 11.6 m. Ground elevation is 2.10 m AMSL(S).

AEN-4/XEN-4

Located southeast of the center of the island, about 160 m west of the south end of the test structure, about 400 m northeast of the old dock on the lagoon beach. Drilled 2/1/74 to 2/7/74 with a mixture of bentonite and Revert to a depth of 28.4 m and cased to total depth with 2-in. PVC. Ground elevation is 2.04 m AMSL(S).

XEN-9

Located at approximately the center of the island about 48 m southwest of AEN/XEN-4. Drilled 2/25/74 to

3/5/74 to a depth of 77 m and cased to total depth. Ground elevation is 2.10 m AMSL(S).

AEN-5

Located 35 m from the lagoon shore, about 300 m northwest of the old dock. Drilled 2/22/74 to a depth of 12.2 m and cased to 11.6 m. Ground elevation is 1.86 m AMSL(S).

AEN-6

Located near the extreme southern tip of the island about 80 m from the lagoon edge and about 15 m north of XEN-8. Drilled 2/23/74 to a depth of 12.2 m and cased to 11.6 m. Ground elevation is 2.26 m AMSL(S).

XEN-8

Located on the extreme southwest tip of the island, 10-15 m south of AEN-6 and about 40-50 m from the lagoon beach. Drilled in late Feb. 1974 to a depth of 54.8 m and cased to total depth. Ground elevation is 2.35 m AMSL(S).

XEN-2

Located about 80 m northeast of the north end of the test building about 350 m west of the seaward beach. Drilled 1/31/74 to 2/7/74 to a depth of 70.3 m and cased to total depth. Ground elevation is 2.68 m AMSL(S).

XEN-3

Located about 15-20 m inland of the lagoon beachline directly behind the old pier, approximately centered along the lagoon shore. Drilled 2/1/74 to 2/7/74 to a depth of 90.8 m and cased to 19.8 m. Ground elevation is 1.65 m AMSL(S).

XEN-5

Located about 300 m northeast of the north end of the test building and about 170 m west of the nearest seaward beach. About 320 m southwest of XEN-1. Drilled 2/11/74 to 2/19/74 to a depth of 64.4 m and cased to total depth. Ground elevation is 2.50 m AMSL(S).

XEN-6a

Located about 170 m northeast of the north end of the test building, 270 m from the seaward beach. Drilled 2/14/74 to 2/15/74 to a depth of 31.6 m and cased to 31.2 m. Ground elevation is 2.62 m AMSL(S).

XEN-7

Located on the extreme northeast tip of the island, approximately 47 m south of the beach. Drilled 2/19/74 to 2/22/74 to a depth of 36.6 m and cased to total depth. Ground elevation is 1.31 m AMSL(S).

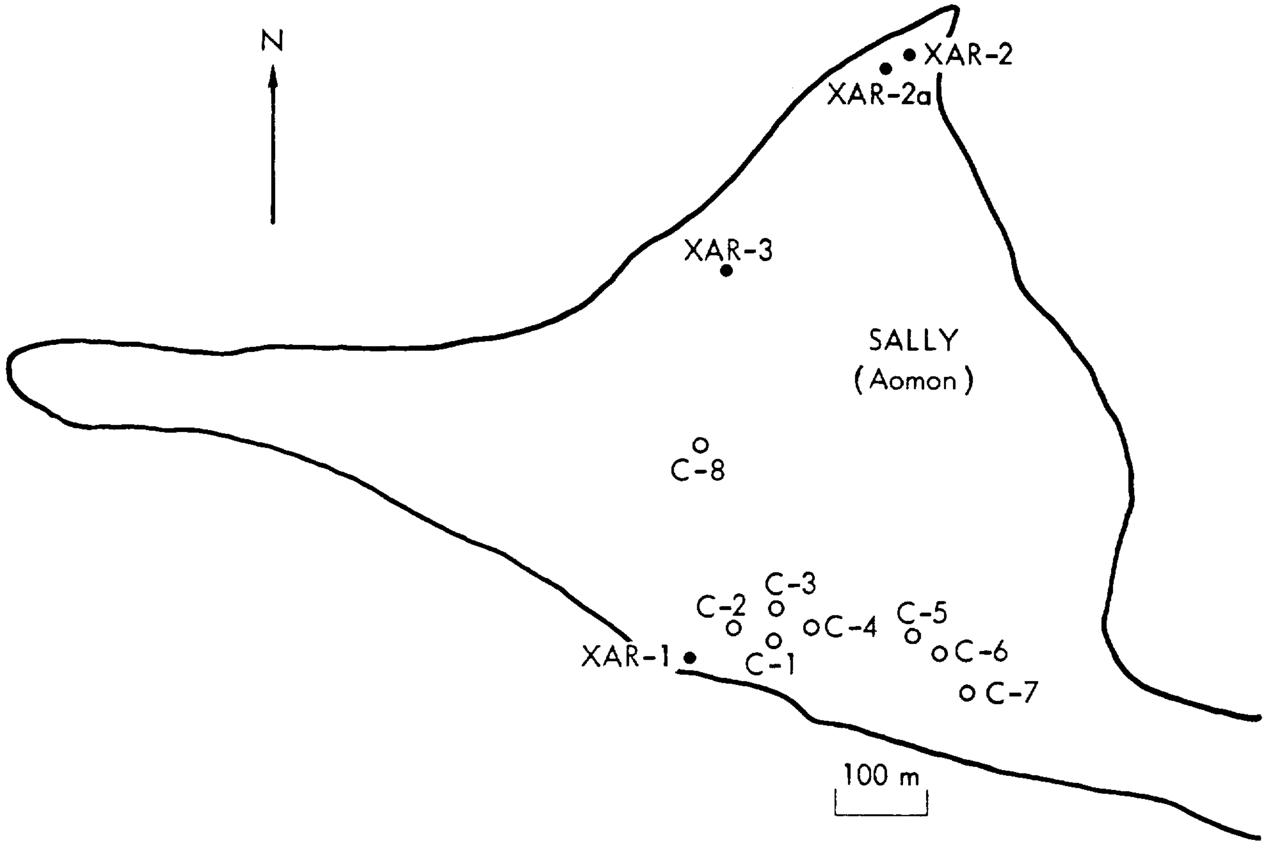

Fig. 4. Well locations on Sally (Aomon), Enewetak.

SALLY (Aomon)

At the beginning of the program Sally, Fig. 4, was not among the islands chosen for the ground water studies. Its small area (0.32 km^2 not including "Sally's Child") would not lead one to expect a freshwater lens of any size and the island had been subjected to considerable earth-moving activity in connection with the PACE program of 1972. However, through the cooperation of project EXPOE personnel, the four 2-in. wells that they drilled for their own purposes were cased with slotted pipe and made available for the ground water studies.

Sally received a total of 1981 R/h fallout from 16 events including 3 surface ground zeros. Soil samples taken during the survey show radioactivity concentrations increasing with depth at some locations and essentially homogeneous at others. These unusual distributions may have resulted from construction activities during the weapons testing period or from PACE excavations. Vegetation has certainly been modified by PACE activities. Between one-third and one-half of the island has been cleared of vegetation and a large basin, excavated to the water table, exposes bare coral sand and beach rock on most of the southern half. The remaining vegetation is typical Messerschmidia and Scaevola scrub growth.

Scattering in the basin are eight water-filled circular craters produced by high explosive charges during the PACE program. These craters average 10 min diameter and are 1-3 m deep. They were sampled several times for whatever additional information they could provide.

The four wells on Sally lie close to a straight line drawn from the NE tip of the island to the center of the lagoon beach.

XAR-1

This well is drilled in an area of sparse vegetation on the lagoon (south) side of the island. It is located approximately at the center of the coast, about 20 m inland from the edge of the vegetation. It was drilled from 4/6/74 to 4/14/74 to a depth of 74 m and cased to a depth of 65 m. Elevation is 1.95 m AMSL.

XAR-2 and 2a

These wells were drilled approximately 12 m apart on the northeastern (ocean side) tip of the island in the middle of a bladed road through relatively dense (for Sally) vegetation. The midpoint between the two wells is about 35 m inland from the intersection of the road and the beach. XAR-2, the more easterly well, was drilled from 4/18/74 to 4/22/74 to a depth of 45 m and cased to a depth of 34 m. XAR-2a was drilled from 4/28/74 to 5/7/74 to a depth of 44 m and cased to unknown depth. Elevation of XAR-2 — 1.40 m AMSL, of XAR-2a — 1.22 m AMSL.

XAR-3

This well is located about 270 m NE of XAR-1 and 380 m slightly west of south from XAR-2/2a. It was drilled from 4/22/74 to 4/26/74 to a depth of 75 m and cased total depth. Elevation - 1.95 m AMSL.

URSULA (Rojoa)

The area of Ursula, Fig. 5 is 0.11 km^2, placing it about midway in size between Leroy and Belle. It received a total fallout of 651 R/h from 12 events, making it second only to Leroy as the least contaminated of the northern islands. Twenty-seven soil samples and four vegetation samples collected during the survey confirm the expectation of low level contamination. ^{90}Sr, ^{137}Cs, and ^{60}Co levels in the soil were less than those found on Leroy while ^{239}Pu levels were higher. Vegetation is relatively dense

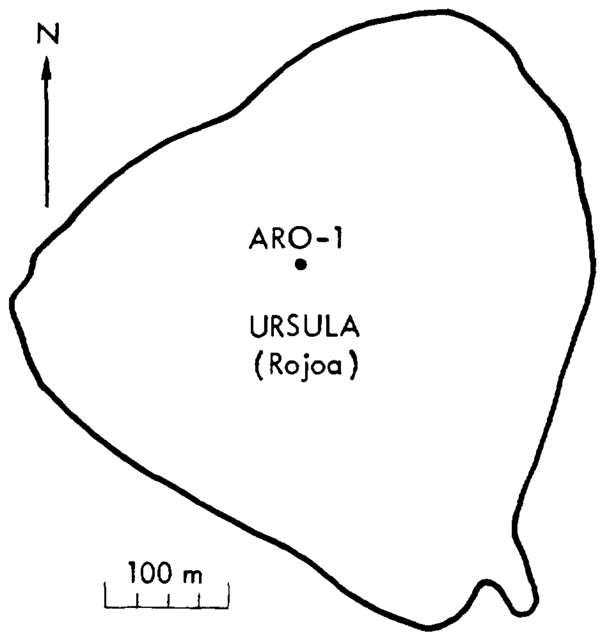

Fig. 5. Well locations on Ursula (Rojoa), Enewetak.

Messerschmidia-Scaevola on the north and western parts of the island and scattered on the southeast third.

Only one well was drilled on Ursula, ARO-1. It is located at the edge of dense vegetation about 50 m NW of the center of the island, and about 235 m along the road that runs slightly N of E from the end of the Ursula-Tilda bridge. It was drilled on 5/15/74 to a depth of 10.5 m and cased to total depth. Elevation - 2.04 m AMSL.

YVONNE (Runit)

Yvonne, Fig. 6, is by far the most contaminated island in the atoll. It received a total of 62 849 R/h of fallout from a total of 24 events including 8 surface ground zeroes. The total fallout is about 6 times what the next most contaminated island (Ruby) received and nearly 20 times the contamination level of Janet. Two nuclear events, Cactus and Lacrosse, conducted on the northern end of the island, produced two water-filled craters. Much of the material ejected from these craters fell out on Yvonne and was subsequently redistributed. In addition to the usual fission and activation products (^{90}Sr, ^{137}Cs, ^{60}Co), high levels of ^{239}Pu contamination produced by another nuclear device, Quince, pose a serious problem over much of the central and northern portions of the island. Soil levels ranging from fractions of a pCi/g of ^{239}Pu up to hundreds of pCi/g were found in the 1972 survey. Construction and clean-up efforts between and subsequent to nuclear events have distributed the contaminants in a highly random fashion. The radiological picture on the northern half of Yvonne is so complex that it was treated as a separate case in the 1972 survey and one should refer to NVO-140 for the detailed information.

With an area of 0.40 km^2, Yvonne is fifth in size in the atoll, but with an average length-to-width ratio of 6:1, it was not expected to support a fresh water lens of any size. Because of the importance of the

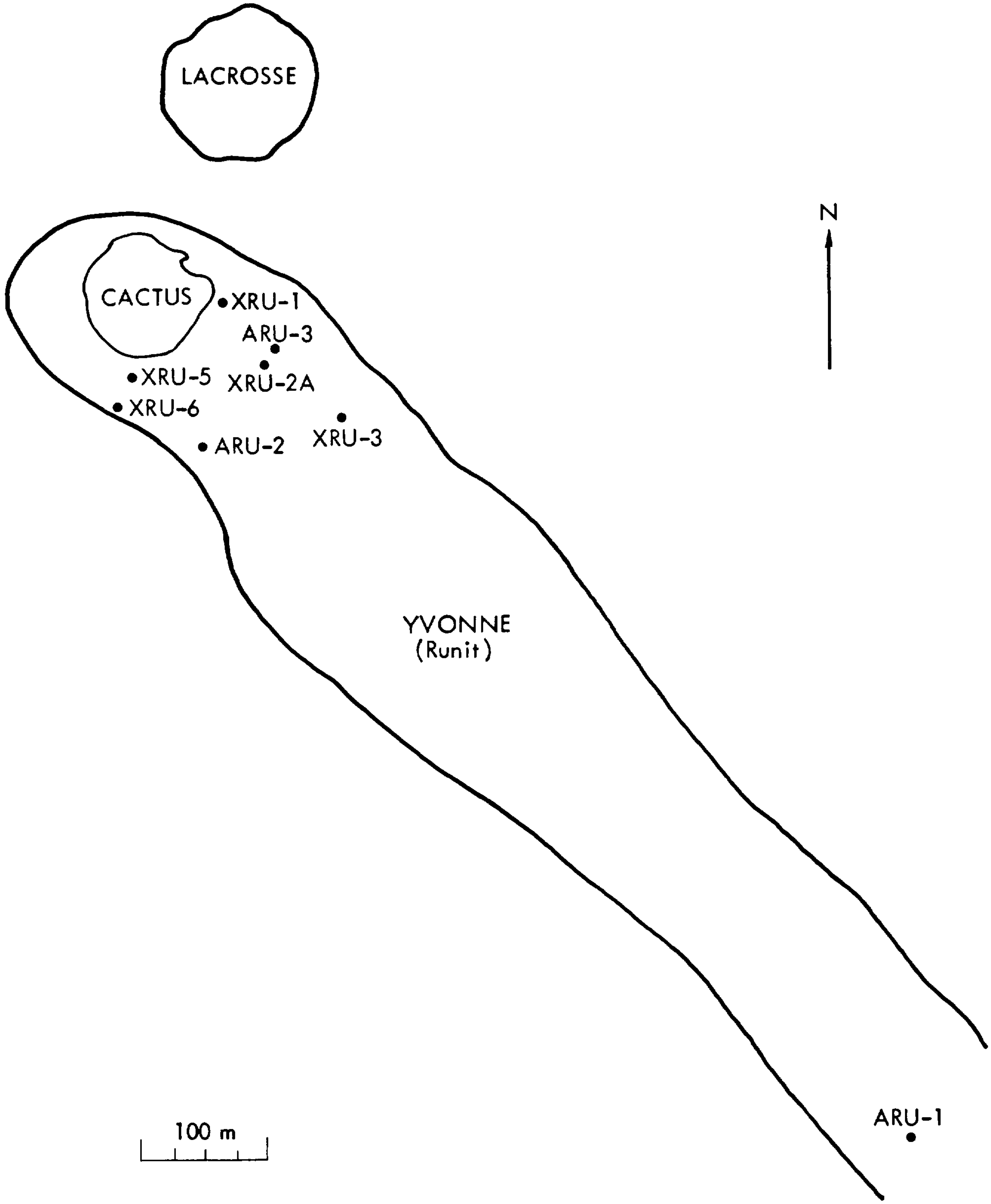

Fig. 6. Well locations on Yvonne (Runit), Enewetak.

investigation of the radiological conditions, both from the standpoint of present distributions as well as future clean-up efforts, three wells were drilled for groundwater studies and five EXPOE wells were set with slotted casing and made available for sampling. The wells are concentrated in the sparsely vegetated area immediately south of Cactus crater, but one well was drilled about one-third the length of the island from Cactus near a suspected Pu burial site.

ARU-1

This is the well drilled near the suspected Pu burial site. It is about 925 m SE from the center of Cactus crater, about 25 m SW of the road and 50 m NE of the lagoon beach. Vegetation is very sparse. The well was drilled on 3/6/75 to a depth of 10 m and cased to total depth. Elevation - 2.2 m AMSL(S).

ARU-2

Located about 125 m from the center of Cactus crater along a line running just east of south. Drilled on 3/7/74 to a depth of 11 m and cased to total depth. Elevation - 2.2 m AMSL(S).

ARU-3

Located about 115 m from the center of Cactus crater along a line running midway between east and southeast. Drilled on 7/15/74 to a depth of 10 m and cased to total depth. Elevation - 2.0 m AMSL.

XRU-1

Located about 65 m due east from the center of Cactus crater. Drilled from 3/6/74 to 3/14/74 to a depth of 53 m and cased to total depth. Elevation - 3.05 m AMSL(S).

XRU-2a

Located about 115 m from the center of Cactus crater along a line running east of southeast. Drilled from 3/8/74 to 3/14/74 to a depth of 50 m and cased to total depth. Elevation - 2.34 m AMSL(S).

XRU-3

Located on essentially the same ESE bearing from the center of Cactus crater as XRU-2a at a distance of about 190 m from the center of the crater. Drilled from 3/14/74 to 3/21/74 to a depth of 73 m and cased to total depth. Elevation - 2.68 m AMSL(S).

XRU-5

Located about 60 m from the center of Cactus crater along a line running west of south. This well is just off the crater lip, about 65 m inland from the edge of the lagoon. Drilled from 3/21/74 to 3/27/74 to a depth of 52 m and cased to total depth. Elevation - 1.83 m AMSL(S).

XRU-6

Located along the same west of south bearing as XRU-5 at a distance of about 90 m from the center of Cactus crater. Drilled from 3/22/74 to 3/29/74 to a depth of 47 m and cased to total depth. Elevation - 1.92 m AMSL(S).

DAVID (Japtan)

This island with an area of 0.44 km^2, Fig. 7, is located at the east channel entrance and was used as a rest area during the test program. It received about 1 R/h of fallout and present background levels are about 1 μR/h over the entire island. No elevated levels of contamination were observed during the 1972 survey in either soil or biota

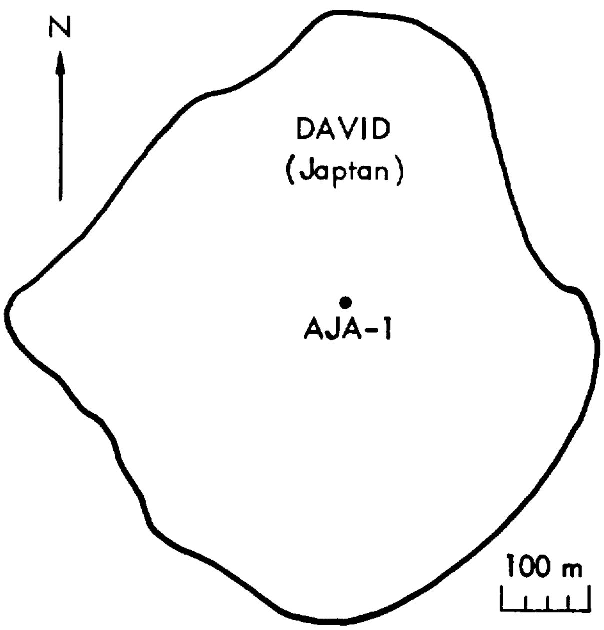

Fig. 7. Well location on David (Japtan), Enewetak.

samples. Since Japtan will probably be the first island resettled by the Marshallese, one well, AJA-1, was drilled to assess water quality and quantity. It is located at the edge of dense vegetation about 50 m south of the center of the island and 50 m northwest from the metal communications building near the center of the island. The well was drilled 3/2/74 to a depth of 11 m and cased to total depth. Elevation - 1.95 m AMSL.

ELMER (Parry, Medren)

Elmer (Fig. 8, area of 0.74 km^2) was used as scientific headquarters during the test programs and received only 2.6 R/h of fallout. Background, soil and biota radioactivity levels are similar to those on David. Like David, Elmer will be among the first islands to be resettled and, at present, is designated for a permanent village. One well, APA-1, was therefore drilled to assess ground-water supply. It is located approximately 220 m southeast of the southern dock and 220 m northeast of the boat ramp. It was drilled 3/1/74 to a depth of 12 m and cased to total depth. Elevation - 4.03 m AMSL(S).

LEROY (Rigili)

Leroy, Fig. 9, is unique in several respects among the islands included

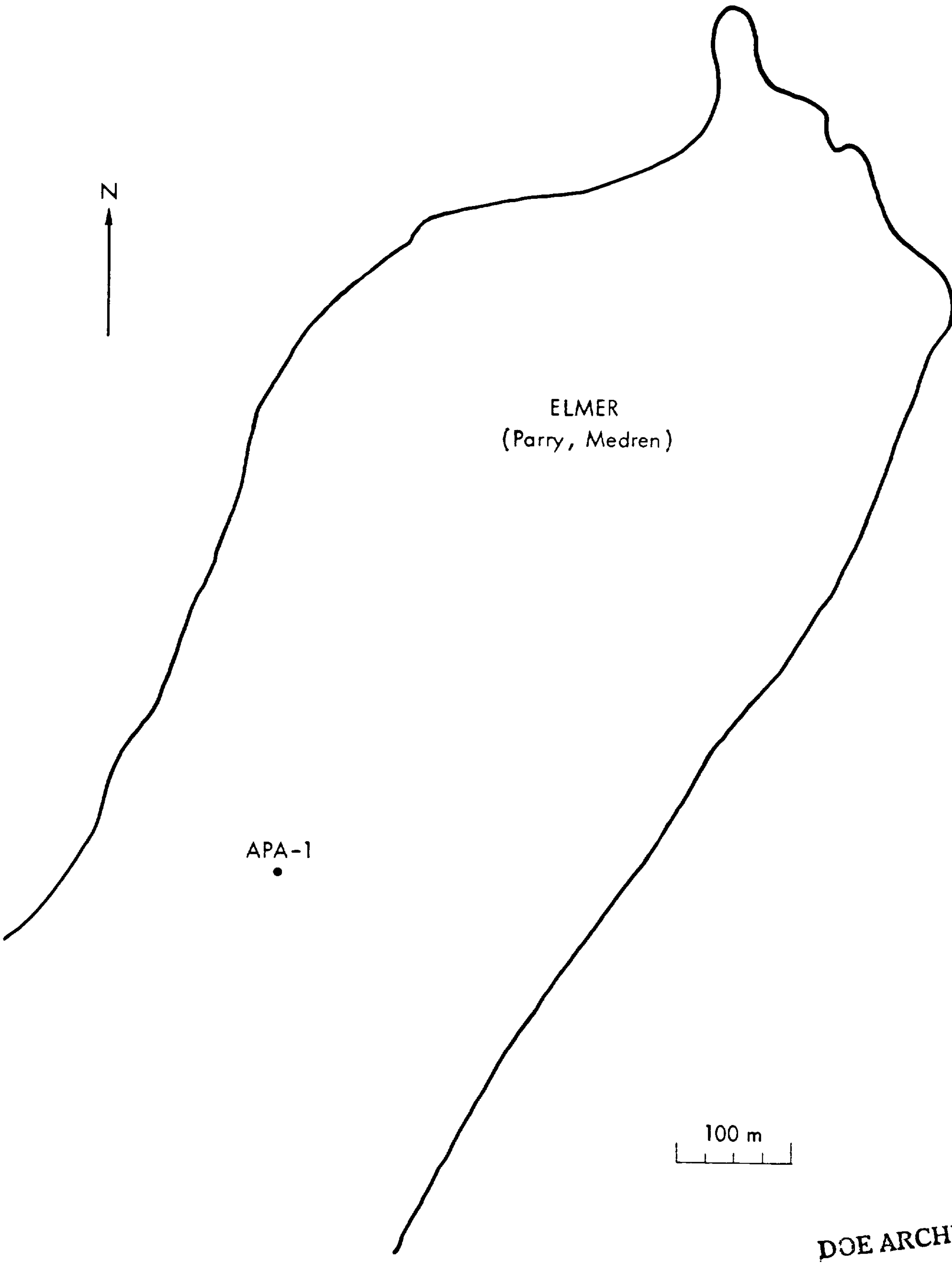

Fig. 8. Well location on Elmer (Parry, Medren), Enewetak.

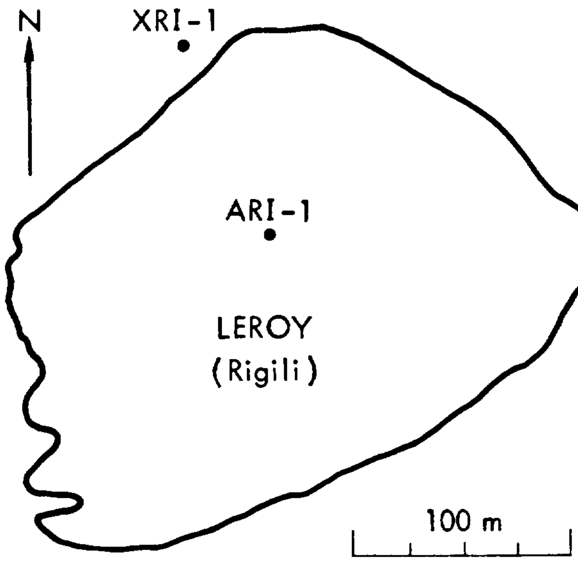

Fig. 9. Well locations on Leroy (Rigili), Enewetak.

in the ground water study. With an area of only 0.065 km^2, it is smallest of all the islands and the only one with a naturally developed, mature covering of vegetation. Large specimens of Pisonia grandis and coconut palm form the dense forest that extends almost to the beaches on all sides. Leroy received a total fallout of 235 R/h from 13 events, placing its level of contamination in an intermediate position, a factor of 100-200 above the clean southern islands, but a factor of 10-100 below the northern islands. Measurements of ^{90}Sr, ^{137}Cs, ^{239}Pu, and ^{60}Co in soil and vegetation samples taken during the survey confirm this intermediate ranking. Two wells have been drilled on Leroy, ARI-1 and XRI-1.

ARI-1

This well is located in an area of dense vegetation on a line due west from the center of the island about 75 m from the center and 50 m inland from the edge of the vegetation. It was drilled on 5/6/74 to a depth of 11 m and cased to total depth. Elevation - 3.05 m AMSL.

XRI-1

This well was drilled in lagoon beach sand on the northwest side of the island. It is approximately 8 m lagoonward from the edge of the vegetation and approximately 50 m southwest of the intersection of the northeast coast and the northwest coast. It was drilled from 5/6/74 to 5/18/74 to a depth of 76 m and cased to 18 m. Elevation - 1.28 m AMSL.

EDNA (Sanildefonso) and
HELEN (Bokaidrik)

These two islands are hardly more than sand bars with a sparse covering of Messerschmidia-Scaevola scrub growth. Areas are difficult to define as the vegetation covers only small parts of the islands and the remainder is constantly being modified by tidal and current action. The area of Edna, Fig. 10, is given in NVO-140 as 2800 m^2. Helen, Fig. 11, was attached to Irene by a sandbar in 1972 and its area was included as part of Irene. From aerial photographs in NVO-140 the area covered by vegetation on Helen can be estimated as about 6250 m^2. The same technique gives an estimate of 6900 m^2 for Edna, which indicates the uncertainty in such estimates.

The principal interest in these

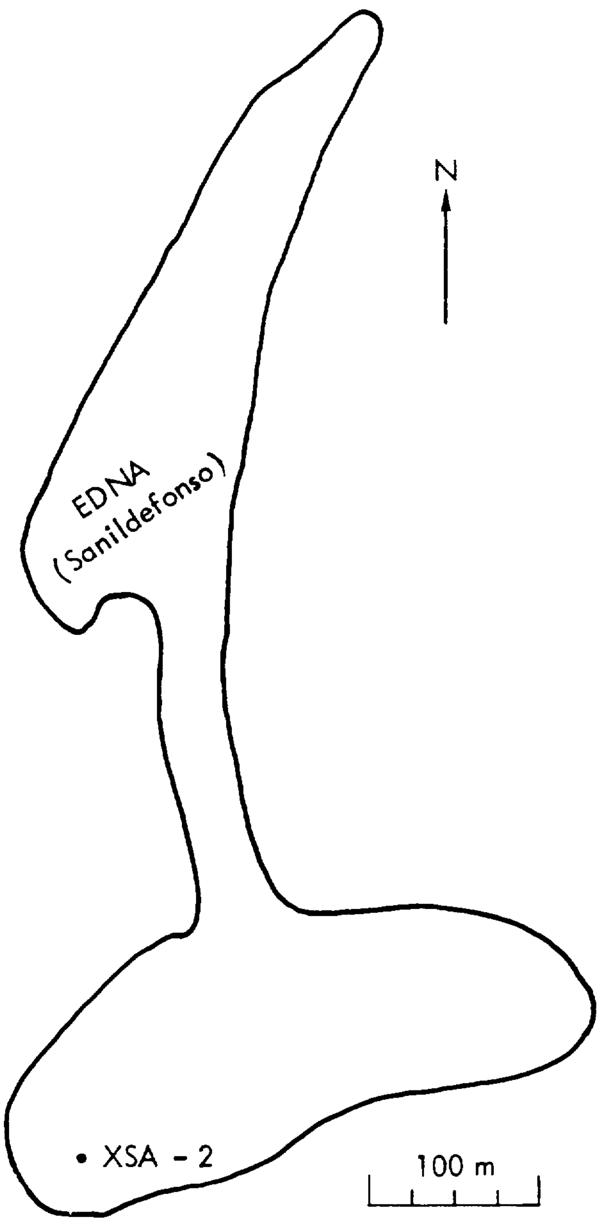

Fig. 10. Well location on Edna (Sanildefonso), Enewetak.

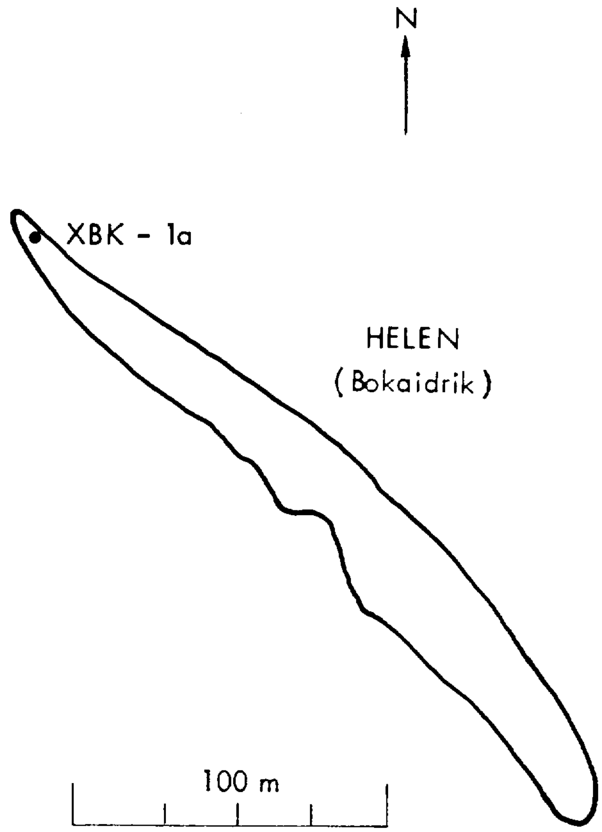

Fig. 11. Well location on Helen (Bokaidrik), Enewetak.

two islands lies in their proximity to the Mike and Koa craters. The craters lie between the two islands with Edna on the southwest side and Helen on the northeast side. Both islands received substantial fallout, Edna 9533 R/h from 16 events. Helen 5277 R/h from 23 events. Average background at 1 m above ground on the two islands was only about 7 μR/h, which is probably explained by the increased leaching due to the exposed and transient nature of these islands.

Neither island was originally included in the ground-water studies.

EXPOE operations made one well on each island available, however.

XSA-2

Located on the extreme southwest tip of Edna approximately midway between the extreme southwest tips of the western and eastern outcroppings of beach rock. Drilled from 6/4/74 to 6/14/74 to a depth of 68 m and cased to total depth. Elevation - 1.59 m AMSL. (XSA-1, on the extreme northern tip of the island, was not cased.)

XBK-1a

Located on the extreme northwest tip of Helen's vegetation about midway across the sandbar. Drilled from 5/29/74 to 6/10/74 to a depth of 76 m and cased total depth. Elevation - 1.68 m AMSL.

Measurements

This section describes the typical field equipment and measurements, methods of sample collection, and types of analysis. Many specific experiments or sampling methods already conducted or planned are described in the text in conjunction with the results.

FIELD INSTRUMENTS

In Situ Conductivity and Temperature Measurements

All wells are routinely probed to qualitatively describe the salinity and temperature profile of the water column. The meter is a portable battery-powered conductivity-temperature meter with a digital readout. Conductivity ranges are 1, 10 and 100 mmho/cm full scale, temperature range/rm -5 to +45°C. Conductivity and temperature sensors are enclosed in a 19-mm by 25-cm plastic probe connected to the electronic package by a 150-m cable. Two spectrographic-grade carbon electrodes are arranged in the probe to form a conductivity cell with a cell constant of about 5 cm^{-1}. Temperature is measured by a resistor-thermistor network (YSI #44202) linear over the range -5 to +45°C. Range switching, signal conditioning, digital output display, and batteries are contained in a 18 × 28 × 18-cm electronic package.

The conductivity cell is calibrated with a lagoon water standard before and usually after each measurement. The temperature probe is calibrated with a laboratory mercury thermometer and measurements are good to ±0.3 K.

Conductivity accuracy, as determined by comparing the computed

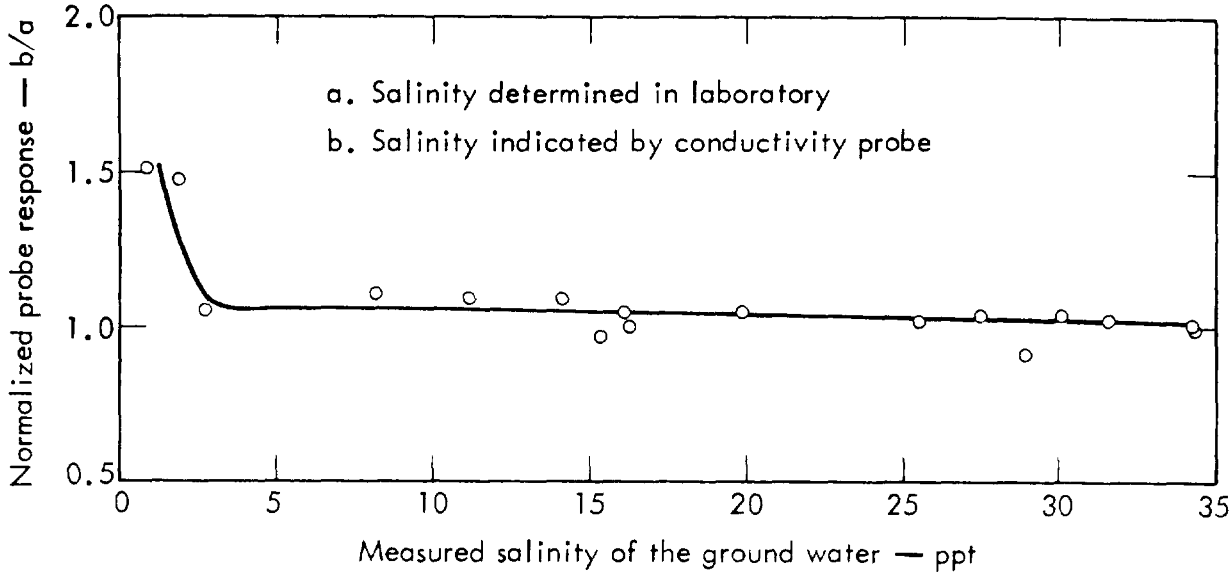

Fig. 12. Conductivity-probe response as a function of salinity in water drawn from wells in coral soil on Enewetak.

salinities from a series of probe measurements to salinity converted from laboratory chloride measurements averaged ±5% over the range 10-36 ppt, (Fig. 12). At lower salinities, deviations of as much as 50% are found between the probe values and the converted chloride values. This difference is explained by the change in composition; at low salinity enough other ions leach from the coral soil to affect the response of the conductivity cell.

It should be pointed out that the probing and sampling are separate operations. With the sharp gradients that were evident in the water column it is difficult, even at low pumping speeds, to maintain a constant salinity during sampling. A considerable fraction of the discrepancy between the Cl^--computed salinity and conductance-probe-converted salinity is due to this effect. During probing operations the probes were agitated by hand to ensure stable and representative determinations.

The conductivity value at the in situ temperature is converted to salinity using Weyl's equations,[2] or the graphs of Fig. 13. The computed salinity was then converted to a percentage of the average lagoon salinity during the sampling period. This type of presentation was useful in the field, at least for the authors, for quickly assessing the relative freshness of the ground water at any depth and for locating the desired sampling depths in the water column. All vertical salinity profiles in this series of reports are expressed in these convenient terms. At the

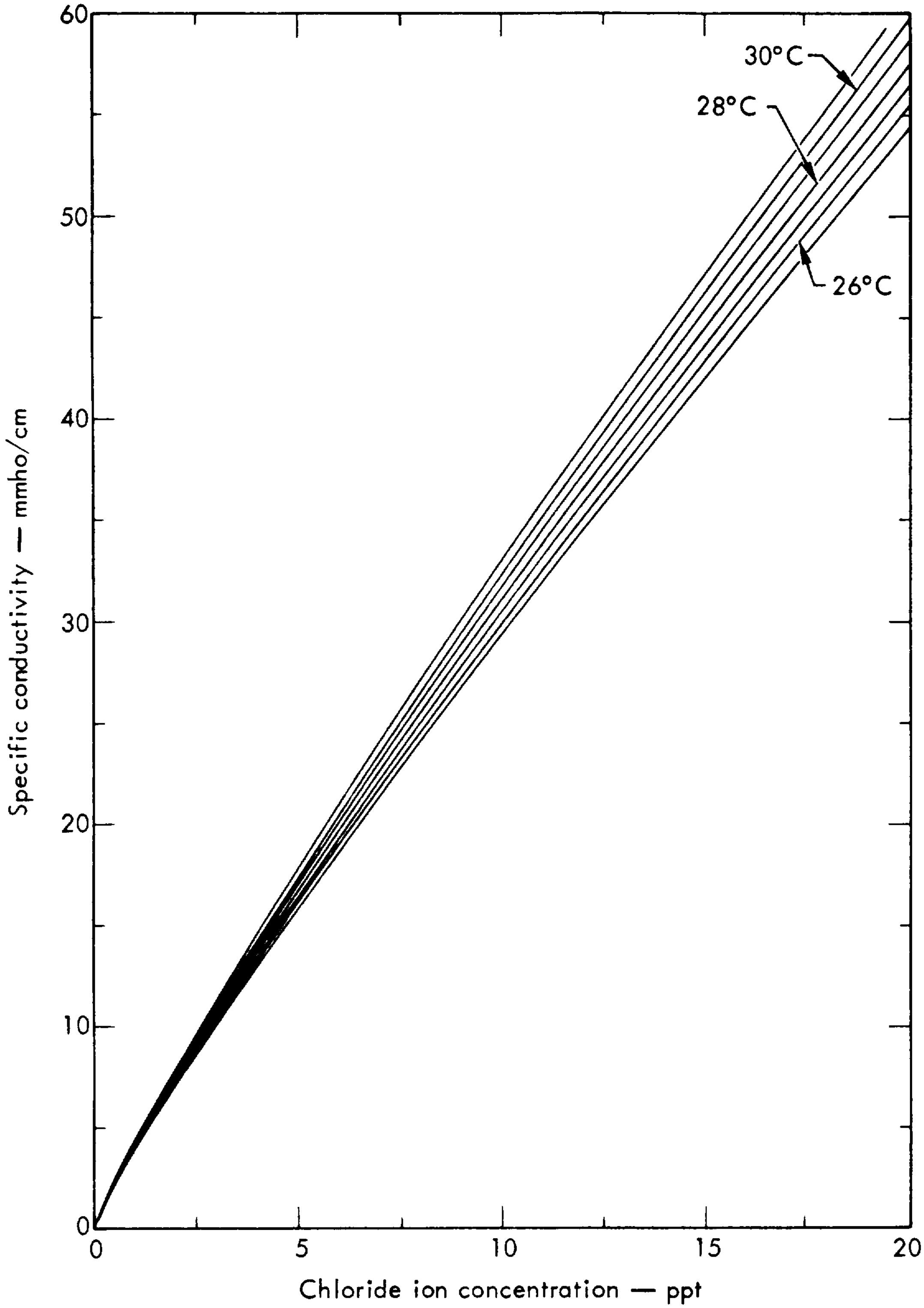

Fig. 13. Relationship between conductivity and Cl^--ion concentration, over temperature range encountered in Enewetak ground water, computed from Weyl's formulas.[2]

same time, we made it a practice to obtain separate samples for absolute salinity determination at specific depths.

Oxygen Probe

All wells are probed to determine the vertical distribution of dissolved oxygen. This is normally done in conjunction with the salinity probe by attaching the O_2 sensor beside (for the 4-in. casings) or immediately above (for 2-in. casings) the conductivity probe. The instrument employed is a battery-operated O_2 meter (YSI Model 51A) connected to a standard pressure-compensated YSI polarographic oxygen detector by a 15-m cable. The field calibration standard is sea water saturated with air at known temperature and salinity; the instrument response is set to tabulated O_2 solubility values. The probe is also equipped with a thermistor, providing separate temperature readout. Instrument accuracy is ± 0.2 ppm O_2 and ± 0.7 K; readability and repeatability are both better than ± 0.1 ppm O_2 and ± 0.3 K. During probing operations temperature and conductivity values are read first and used to set the O_2 meter salinity and temperature compensation controls. During measurement, the probes are agitated by hand to ensure stable and representative O_2 determinations.

pH Meter

Water samples are analyzed with a battery-operated Beckman Electromate pH meter with a Beckman combination pH electrode. The unit is accurate to ± 0.08 pH units, and readable and reproducible to ± 0.02 pH units. Measurements are normally made in the field, with standardization against commercial buffer solutions before and after each measurement. However, it is occasionally necessary to make the initial pH determination in the laboratory 1-8 h after sampling. Values obtained in this fashion are designated by an "L" suffix in the data summary.

Rain Gauges

Remote-recording rain-gauge units have been situated on the islands of Janet, Leroy, and Fred to determine whether or not there is any systematic variation in rainfall around the atoll and to intercalibrate with the rain observations routinely made by the U.S. Coast Guard on Fred. The units consist of a standard Weather Measure Corp. P-501 tipping bucket rain gauge connected to a sealed instrument package containing a power supply (four 12-V dry cell batteries), dessicant, a crystal oscillator timing circuit, and a Practical Automation 6-digit printer (Model MMP-6). Each tip of the rain-gauge bucket (equivalent to 0.25 mm rain) is stored in the printer's mechanical registers, and the accumulated total is printed out once a day on signal from the clock timing circuit.

Tide Gauges

Six Stevens Model 51 tide recorders were turned over to the project by USAF/USGS personnel when project EXPOE was terminated. These are currently in use to measure tidal efficiency and phase lag in selected wells. They are Negator spring-driven recorders with Chelsea clock timer/regulators, a chart speed of 6.1 cm/day (maximum time resolution is about 15 min) and 6:1 pen travel reduction.

WATER SAMPLING PROCEDURES

A battery-operated pump draws ground water from a predetermined depth through a tygon tube to the ground surface. A variable speed control permits pumping rates from 1-8 l/min. Either filtered or unfiltered water can be collected from the sampling manifold. A separate hose is used on each island and the entire system is adaquately purged at each well before sampling to minimize contamination.

Depending on the island and type of analysis, a series of samples ranging in volume from 25 ml to 55 l are withdrawn for measuring radionuclides, major and minor elements, nutrients, bacteria and suspended material. Unless suspended material and bacteria samples are desired, all water is first filtered through a 0.4-μ Nuclepore filter. On occasions, a 1-μ filter has been used ahead of the 0.4-μ filter when a heavy suspended load was encountered or a large volume of water was filtered. The total volume through the filter is monitored and the filter(s) subsequently analyzed for the quantity of radionuclides associated with the filtered material.

ANALYTICAL PROCEDURES

Radionuclides

Concentrations of ^{90}Sr, ^{137}Cs, ^{60}Co, ^{207}Bi, ^{155}Eu, and the transuranic elements are determined in the particulate material and the filtered lens water. Filtered water is acidified to pH 1 in the field and returned to the laboratory for processing. Standardized mixed carrier solutions are added to the acidified sample and equilibrated by stirring for 6 h. Cesium is extracted from the solution by absorption on ammonium molybdophosphate (AMP). Then sodium hydroxide is added and the precipitated Co, Bi, Fe, rare earths, and transuranic elements are separated by decantation and centrifugation. After adjusting the solution to pH 9, strontium and calcium are precipitated with oxalic acid. The hydroxide fraction is directly counted on a low-level Ge(Li) spectrometer without further purification to assess the levels of ^{60}Co, ^{207}Bi, ^{155}Eu, and other gamma emitters present in the sample.

The cesium fraction is further purified by dissolving the AMP with NaOH and performing a ferric hydroxide scavenge. Cesium is reprecipitated from a weakly acid solution with AMP and this fraction is counted on a gamma spectrometer.

The strontium oxalate fraction is decomposed with boiling concentrated nitric acid and separated from the residual calcium as Sr $(NO_3)_2$. After repeated nitrate and scavenging steps, Y^{90} is allowed to grow in from its ^{90}Sr parent. Yttrium carrier is added to the purified strontium fraction and precipitated as the hydroxide. The hydroxide is dissolved and loaded on a Dowex 50 cation exchange column. After washing the column with water, Yttrium is removed from the column at a pH 5 with 0.5M alpha-hydroxy-iso-butyric acid, precipitated as the oxalate, ignited and weighed as the oxide, and counted on low-background beta detectors. Chemical recoveries of Co, Bi, Cs, and Sr are determined by atomic absorption.

The plutonium isotopes and americium 241 are separated from the hydroxide fractions and purified on anion exchange columns.[3,4] The subsequently purified fractions are plated and counted on alpha spectrometers.

The filtered particulate sample is dried and ashed at 450°C for 24-48 h. The ash is counted directly on a Ge(Li) spectrometer for ^{137}Cs, ^{60}Co, ^{207}Bi and any other gamma-emitting radionuclides. The ash is then dissolved in nitric acid and strontium carrier, ^{236}Pu and ^{243}Am tracers are added and equilibrated. Strontium, plutonium and americium are separated, purified and determined as above.

Water for the tritium determination is extracted by sublimation from a frozen aliquot. The amount of tritium is measured either by gas counting or by scintillation counting.

Major and Minor Ions

Cations are determined by atomic absorption spectrophotometry (AAS), using a Perkin-Elmer model 303 AA spectrophotometer with a C_2H_2-air flame. For K, Na, Mg, and Ca, approximately 20 ml of sample is diluted to put concentrations in the most convenient working range for the determination (dilution factor is estimated on the basis of chloride concentration) and all four ions are determined at the same dilution level.

Secondary absorption lines are used for Na and Mg to reduce interferences and to permit analyses of all the ions on the same dilution. Concentrations are determined from a calibration curve based on mixed commercial standard solutions. Sr and Rb are also analyzed by AAS, but at lower dilution levels and by standard addition rather than calibration curve methods.

Total alkalinity is determined in the field, normally on the evening of the day the sample was collected. The method used is titration with standardized dilute H_2SO_4, with potentiometric endpoint determination using the pH meter described above.

Chloride concentrations were determined by titration with mercuric nitrate at a fixed pH, using a mixed-indicator reagent to determine the endpoint.[5]

The method used for sulfide analysis is a portion of the method of Johnson and Nishita[6] for the microestimation of sulfur. To isolate and prevent oxidation of sulfide ion between the time of sampling and the time of analysis, field samples of 20 ml of water are placed in bottles already containing 5 ml of the zinc acetate-sodium acetate absorbing solution. In the lab the sulfide is filtered out on glass fiber filters as ZnS. The filter ZnS is placed in a beaker containing the amine and ferric-ion solutions to convert to methylene blue. The resultant solution is transferred to a volumetric flask, diluted to volume and the absorbance is measured on a Beckman DU spectrophotometer at 600 nm. The sulfide-ion concentration is determined by comparison with a standard calibration curve, prepared by analysis of several dilutions of a saturated solution of $Na_2S \cdot 9H_2O$.

Sulfate analysis is carried out on the filtrate remaining after the removal of the ZnS. The method used is that of Dunk et al.,[7] an indirect determination whereby an accurately measured excess of $BaCl_2$ is added to the sulfate-containing sample and the excess barium is determined by atomic absorption spectrophotometry.

Nutrients

In the field an aliquot of the filtered water is placed in a brown, acid cleaned, polycarbonate 130-ml bottle and iced immediately. It is frozen within 8 h and kept frozen thereafter until analyzed. Analyses for NH_3, NO_3^-, $Si(OH)_4$, and $PO_4^=$ are done on a Technicon II autoanalyzer using standard seawater techniques as modified for that instrument.[8]

Bacteria

In wells with water of potable or near potable quality, total coliform concentrations are estimated by sampling an aliquot of unfiltered water into a sterile container, refrigerating it, and processing it the same day through a Millipore portable water quality lab kit (XX63001150) using standard filtration and incubation techniques.[9]

References

1. Enewetak Radiological Survey, U.S. Atomic Energy Commission Nevada Operations Office, Las Vegas, Nevada, Rept. NVO-140 (1973).
2. P. K. Weyl, Limnol. Oceanogr. 9, 75 (1964).
3. K. M. Wong, Anal. Chim. Acta. 56, 355 (1971).
4. R. Bojanowski, H. Livingston, D. Schneider, and D. Mann, "A Procedure for Analysis of Americium in Marine Environmental Samples," Ref. Meth. Marine Radioactivity Studies, II, IAEA, Vienna, (IAEA Technical Report Series, in press 1975).
5. Standard Methods for the Examination of Water and Wastewater, 13th ed. (Amer. Public Health Assoc., Amer. Water Works Assoc., Water Pollution Control Federation, 1971).
6. C. M. Johnson and H. Nishita, Anal. Chem. 24, 736 (1952).
7. R. Dunk, R. A. Mostyn, and H. C. Hoare, At. Absorp. Newsl. 8, 79 (1969).
8. J. D. H. Strickland and T. R. Parsons, A Practical Handbook of Seawater Analysis (Fisheries Research Board of Canada, Ottawa, 1968).
9. Biological Analysis of Water and Wastewater, Millipore Corporation, Bedford Mass., Application Manual AM302 (1973).

Appendix A

Criteria for Potable Water

The reports that follow will present a general description of the results of our chemical and radiological analyses of the Enewetak ground water. In the case of potentially potable water a standard needs first to be defined. The following recommended limits, quoted directly from U.S. Public Health Service Publication No. 956,* are provided only as a reference.

(a) The following chemical substances should not be present in a water supply in excess of the listed concentrations when other more-suitable supplies are or can be made available.

	mg/l
Chloride	250
Nitrate	45
Sulfate	250
Total dissolved solids	500

(b) The Advisory Committee, in considering limits which should be established for drinking water, recommended limits for only two radionuclides, Radium-226 (3 pCi/l) and Strontium-90 (10 pCi/l).

(c) Coliform colonies per standard sample shall not exceed 3/50 ml, 4/100 ml, 7/200 ml, or 13/500 ml in:

(1) Two consecutive samples.

(2) More than one standard sample when less than 20 are examined per month.

---

*<u>Drinking Water Standards</u>, U.S. Public Health Service, Pub. 956 (1962).

RBC/lc/lmc